

REMARKS

This communication responds to the Office Action of July 17, 2008 in which the Examiner rejected claims 1-32 and 51-57. In this response, claim 1 is amended without prejudice. Specific support for this amendment is found in the as-filed specification. No new matter is added by way of this amendment.

Claims 1-32 and 51-57 are rejected under 35 USC § 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which Applicant regards as the invention. Specifically, it is unclear to the Office what is meant by “ceramic-type anode layer.”

This rejection is overcome, at least, for the following reasons.

First, Applicant notes that ceramic-type materials used for anodes are well known to those of skill in the art. See, for example, “Ceramic Anodes for Corrosion Prevention”, U.S. Army Corps of Engineers, provided herewith for the Examiner’s convenience as Appendix I. Further, the specification discusses various types of ceramic or “cermet” materials used for solid oxide fuel cells at, for example, pages 2-3. However, in the interest of furthering prosecution and without prejudice, claim 1 has been amended herein to recite that the anode side comprises an anode layer comprising a ceramic material. Therefore, the rejection is overcome and should be withdrawn. Applicant respectfully requests same.

Claims 1-32 and 51-57 are rejected under 35 USC § 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which Applicant regards as the invention. Specifically, it is unclear to the Office what is meant by “green material.”

This rejection is overcome, at least, for the following reasons.

First, Applicant notes that one general meaning of the term “green” when used in the English language is:

7. Not seasoned; not dry;

Webster Dictionary, 1913.

Further, when used in a technical capacity specifically directed to the field of ceramics, “green” is used to connote parts that are “soft plastic, pliable, and will over time lose its shape.” See, “Ceramic engineering” at page 2, Wikipedia.org, provided herein as Appendix II for the Examiner’s convenience. Further attached hereto as Appendix III, for the Examiner’s convenience, is a second article from Wikipedia from the section on “Ceramics.” Page 5 of this article describes the production of a “green” body and its curing by the process of “sintering.”

Finally, in the interests of confirming that the Office has previously examined and allowed claims using the word “green” in the context of ceramic or cermet materials, the Office’s attention is directed to U.S. patent 6,221,289 to Corbett et al. (the ‘289 patent). As discussed in the present specification at, for example, pages 3-5, the ‘289 patent describes that a ceramic composition comprises a ceramic powder and a binder to form “green” elements for shaping and firing. See, ‘289 patent, abstract. Further, the ‘289 patent discusses how “sintering” of the “green” material results in the ceramic particles becoming bound together. ‘289 patent col. 1- col. 4. Thus, Applicant submits that the term “green”, as used herein with respect to the formation of ceramic pieces, is a well understood term in the field of art and, further, its meaning in this respect is recognized by the Office.

To be complete, Applicant notes that “sinter” is a well accepted word in the English language defined as:

- **verb** cause (a powdered material) to coalesce by heating (and usually also by compression), without melting.

Compact Oxford English Dictionary, © Copyright Oxford University Press, 2008.

Thus, Applicant submits that, in fact, the term “green material” is well understood by those of skill in the art, and additionally, the U.S. Patent Office. The rejection is thus overcome and should be withdrawn. Applicant respectfully requests same.

Claims 1-8, 17-21, 51-57 are rejected under 35 USC § 103(a) as being unpatentable over Dodge (WO 96/04690) in view of Singh et al. (U.S. Patent No. 4,894,297).

This rejection is overcome, at least, for the following reasons.

The Office Has Misinterpreted The Claim

In the Office action at page 3 the Office states, “the term ‘preformed’ is functional language and imparts intended use to the structural features of the product. Therefore, while the intended use language of the claim has been considered, it is not given patentable weight because it is directed to a process and not directed to the structural features of the product.” This statement is incorrect. Further, Applicant submits that the Office apparently has misunderstood the structural features derived from an “embedded” anode side current collector derived from the preformed tubular structure because the Office has, apparently, misunderstood the term “green” as used by those of skill in the art of ceramics. This is discussed below. Further, the Office continues its rejection by saying that “[A] claim containing a recitation with respect to the manner in which a claimed apparatus is intended to be employed does not differentiate the claimed apparatus from a prior art apparatus if the prior art apparatus teaches all the structural limitation of the claim.” In support of this statement, the Office cites to MPEP 2113. However, MPEP 2113 is directed to a product by process claims. In the instant case, the claim describes that the tubular metallic structure is “at least partly embedded in the anode layer and reinforces the anode layer.” This “structural feature” of the invention is derived from the fact that the tubular metallic structure is embedded in the anode layer, which is made possible because the anode layer is applied to the tubular metallic structure while it is ‘green’ before it is sintered.” Therefore, Applicant submits that, first, the claim does not recite a product by process claim; and second, the claim does recite structural language which does distinguish the present invention from the prior art.

Dodge Discloses A Hydrogen Fuel Cell, Not A Solid Oxide Fuel Cell

Dodge discloses a “hydrogen fuel cell assembly employing a wet perfluorsulfonic acid electrolytic membrane.” See, Abstract. This particular type of hydrogen fuel cell is also known as a “Polymer Electrolyte Membrane Fuel Cell” (PEMFC) or a “Proton Exchange Membrane Fuel Cell” (PEMFC). Instant claim 1 and claims 2-8, 17-21 and 51-57, which depend ultimately therefrom, *require* the invention to be a “tubular solid oxide fuel cell.” While these different types of fuel cells share the characteristic of producing electricity by the oxidation of a fuel, they are not interchangeable and/or compatible with each other. In this regard, the Applicant provides herewith, for the Examiner’s convenience, a survey of different types of fuels cells from “fuel

cell works” as Appendix IV, available on the internet at: <http://fuelcellsworks.com/typesoffuelcells.html>. As described in Appendix IV, there are at least 9 major kinds of fuel cells, two of which are the “Polymer Electrolyte Membrane” (PEM) and the “Solid Oxide.” Further, as discussed in Appendix IV, the fuel source for the PEM is hydrogen. This is also stated by Dodge: “Disclosed embodiments include a self-contained portable fuel cell in which the cell is shaped to accommodate a canister of hydrogen fuel and an array of cell arranged around a common hydrogen fuel tank or canister.” Dodge, Abstract. Thus, the fuel type used by Dodge is explicitly recited as well.

That Dodge describes a PEM fuel cell is explicitly stated. “In my U.S. Patent No. 5,336,570 . . . I disclosed a lightweight and portable hydrogen fuel cell of the proton-exchange membrane type. . . . drawbacks of the constructions set forth in my U.S. Patent ‘570 relate to ease and cost of fuel cell of the type disclosed in my U.S. Patent ‘570 which was easier and less expensive to manufacture. It would furthermore be desirable to have a fuel cell of the type disclosed in my Patent ‘570 which was easier and less expensive to manufacture.” Id. at page 2, lines 19-42. “In accordance with the invention, an easy to manufacture, light-weight fuel cell” that “promote engagement of the electrodes with the cells’ electrolytic membrane is provided.” Id. at page 3, lines 34-39. “[T]he invention provides a hydrogen fuel cell which is shaped to receive and embrace a hydrogen supply canister to provide a self-contained portable electricity generating unit.” Id. at page 4, lines 26-29 (emphasis added). Further, “[I]n the embodiment of Figure 2, flat laminar fuel cell assemblies 860, each comprising a proton exchange membrane sandwiched between cathodic and anodic electrodes are interspersed between gas-distribution plates 862.” Id. at page 10, lines 29-33 (emphasis added).

Dodge Would Not Function with a Solid Oxide Electrolyte

Further, Applicant points out that solid oxide fuel cells and PEM fuel cells are not compatible. This is true for several reasons, not the least of which is that PEM require pure hydrogen which must be provided, typically, in the form of a compressed gas, requiring the provision of a “hydrogen supply canister” as described by Dodge (see, above). Further, as discussed in Appendix II, PEM fuel cells use a solid polymer as an electrolyte (e.g., the electrolytic membrane) and porous carbon electrodes containing a platinum catalyst. In contrast, a solid oxide fuel uses a “solid oxide” as the electrolyte and as is required by the claims, and an

oxide as the fuel type. This requirement is clearly shown in the schematic on page 4 of Appendix IV. Thus, the electrolyte of one fuel cell would not work as the electrolyte of another fuel cell type. Nor would the fuel of one cell type function as the fuel of the other cell type. Thus, Dodge can not work to make the present invention obvious as Dodge teaches a different type of fuel cell with different requirements, different fuel, different electrolyte, different operating temperatures, different anode, different cathode, etc. Dodge simply provides none of the element required of a solid oxide fuel cell.

Singh Does not Remedy the defects of Dodge

While Singh does disclose a solid oxide fuel cell, the fuel cell described by Singh includes, from the inside out, a tubular support tube, a cathode deposited onto the support tube, an electrolyte deposited onto the cathode and an anode. In contrast, the instant claims *require*, from the inside out, an anode side current collector at least partially embedded in an anode layer, the anode layer having a solid oxide electrolyte applied thereto, a cathode layer followed by a cathode side current collector. Thus, the very structure of Singh is different in, at least, requiring a non-functional support tube, a cathode where the instant anode side-current collector/anode is found in the present invention and an anode and anode current collector is found in the present invention. Thus, Singh does not teach all the elements of the present claim, nor could Singh be modified to do so, as Singh requires at least a non-operational tube functioning only as a mechanical support. The rejection is therefore overcome and should be withdrawn. Applicant respectfully requests same.

The Combination of Dodge and Singh Does Not Yield the Present Invention

Claim 1 and claim 2-8, 17-21 and 51-57, depending therefrom, *require* a solid oxide fuel cell comprising an anode side defining a tubular passage, a ceramic-type anode layer, an anode-side current collector in electrical contact with the anode layer and at least partially embedded therein, a solid oxide electrolyte layer on a radially outer surface of the anode layer, a cathode layer on a radially outer surface of the electrolyte layer and a cathode-side current collector on the cathode layer. One embodiment of this arrangement is illustrated in Fig. 1 of the application.

As discussed above, Dodge does not disclose a solid oxide fuel cell and, thus, cannot use a solid oxide electrolyte layer. As discussed by Dodge, the electrolyte is a wet perfluorsulfonic acid electrolytic membrane. See, for example, the Abstract. Further, where the hydrogen fuel

cell of Dodge is tubular the innermost component is simply a “hollow” member (910). See for example, page 11, line 13. The porous member provides a support for a “first conductive winding 916”, which is titanium wire having a platinum coating or a platinum plating. Thus, the anode is not ceramic and is not tubular but is, rather, wound around a tubular support. Further, in Dodge the electrolyte layer is a perfluorosulfonic acid film (such as Nafion). Significantly, this type of electrolyte layer has operating temperatures of only up to 190° C. (See, for example, Nafion: Physical and Chemical Properties, <http://www.permapure.com/TechNotes/Nafion%20physical%20chemical.htm>). Significantly, Nafion-type electrolytic membranes are not oxides at all but a sulfonated tetrafluorethylene copolymer.

Singh, similarly, discloses only a tubular support member that is mechanical but not operative. As discussed above, the elements of Singh are, further, in the wrong order to result in the present invention. Finally, if Singh were combined with Dodge, not only would the result not be operable but, further, it would not result in the present invention, not least because both Dodge and Sing require a non-functional hollow support tube that are further surrounded by elements not disclosed, required or functional in the present invention. Thus, the rejection of Dodge in view of Singh is overcome and should be withdrawn.

The Office Has Failed To Make A Prima Facie Case Of Obviousness

Because the Office bases the rejection on the conclusion that “Dodge discloses . . . a tubular solid oxide fuel cell” and because Dodge clearly does not disclose a “solid oxide fuel cell.” The Office’s *prima facie* case is not tenable. Further, Applicant notes that not only are the fuel sources of the PEM and the SOFC incompatible, these different fuel cells operate at very different temperatures. Specifically, Applicant directs the Office’s attention to Dodge: “[T]ubular and tapered tubular embodiments of the fuel cell, such as those shown in Fig. 13, are particularly well adapted to function at relatively low, albeit elevated temperatures (circa 80-100° C), with wet-operating electrolytic membranes.” Page 30, lines 25-28 (emphasis added). While this operating temperature is exactly within the range for PEMFC identified in the chart comparing various fuel cell types, the operating temperature for SOFC is 600-1000° C. Further, this is expressly stated in the present application, SOFC’s operate in the vicinity of 700-1000° C. Pg. 2, line 1. Further, while a decrease in operating temperatures for SOFC’s would be desirable, such SOFC’s have not been developed. Again, the Office’s attention is directed to

Appendix IV, Scientists are currently exploring the potential for developing lower-temperature SOFC's operating at or below 800° C . . . however, and stack materials that will function in this lower temperature range have not been identified." See, Appendix IV at page 3. Therefore, Dodge could not operate at the temperature levels required for a solid oxide fuel cell, even if it could conceivably be modified to do so. One of skill in the art might hazard a guess at what would happen to a canister of hydrogen heated to a temperature of 800-1000° C. For this reason alone, the rejection is overcome and should be withdrawn. Applicant respectfully requests same.

Singh Is Incompatible With Dodge

As discussed above, Dodge discloses a PEM fuel cell that operates at the relatively low, albeit elevated temperatures (circa 80-100° C). In contrast, Singh discloses electrochemical cells that have a solid oxide electrode and are operated at over 800° C. See, Abstract. Thus, Applicant submits that the combination made by the Office simply would not work, not least because Dodge requires a different fuel type and Dodge requires an anode that comprises a wet membrane. See Dodge, page. 19, line 43-page 20, line 1. Dodge, simply requires an operating temperature that is far below that of Singh, neither, is compatible with the other. Thus, the combination of Dodge in view of Singh simply does not result in the present invention which comprises "A tubular solid oxide fuel cell." Therefore, at least for this reason, the rejection is overcome and should be withdrawn. Applicant respectfully requests same.

The Combination Made by the Office Is Inoperable

Finally, Applicant points out that the combination made by the Office simply cannot work. First the Office states that "the arrangement of the solid oxide fuel cell of Singh has been reversed into an inverted cell structure from that of the solid oxide fuel cell of Dodge. However, the components are the same and perform the same function even in the reverse order." Office Action at page 4. This is a patently inapposite statement. As discussed above, Dodge does not disclose a solid oxide fuel cell. Dodge requires operating temperatures of between 80 and 100° C. There is simply no way that Dodge could be modified by Singh to result in a solid oxide fuel cell. There is no way that a solid oxide fuel cell could operate at "*elevated*" temperatures of between 80-100° C. One of skill in the art could not combine Dodge and Singh and arrive at a tubular solid oxide fuel cell of the present invention. Therefore, for this reason alone, the rejection is overcome and should be withdrawn. Applicant respectfully requests same.

Claims 9-16 are rejected under 35 USC § 103(a) as being unpatentable over Dodge (WO 96/04690) in view of Singh et al. (U.S. Patent No. 4,894,297) as applied to Claims 1-8, 17-21, 51-57 above, and in further view of Will (U.S. Patent No. 4,347,429).

This rejection is overcome, at least, for the following reasons.

Will Does Not Rectify The Deficiencies Of Dodge And Singh

The combination of Dodge and Singh is inoperable. As discussed above, Dodge does not disclose a solid oxide fuel cell and Dodge could not be modified to result in a solid oxide fuel cell. Singh does not rectify the deficiencies of Dodge and the two simply could not be combined to form any functional type of fuel cell.

Will does not disclose a tubular solid oxide fuel cell. Will discloses an electrode boiler containing an aqueous electrolyte provided with a pair of spaced electrodes immersed in the electrolyte and connected to an AC power source. Neither Dodge nor Singh, alone or in combination, disclose a tubular solid oxide fuel cell. Therefore, the addition of Will cannot make obvious the independent claims and, further, the rejection of dependent claims 9-16 cannot stand. The rejection of claims 9-16 being thus overcome, withdrawal of the rejection is respectfully requested.

Claims 22-27 are rejected under 35 USC § 103(a) as being unpatentable over Dodge (WO 96/04690) in view of Singh et al. (U.S. Patent No. 4,894,297), as applied to Claims 1-8, 17-21, 51-57 above, and in further view of Isenberg (EP 0055016 A1).

This rejection is overcome, at least, for the following reasons.

Isenberg Does Not Remedy The Defects Of Dodge And Singh

The combination of Dodge and Singh is inoperable. As discussed above, Dodge does not disclose a solid oxide fuel cell. Dodge is incompatible with Singh. The combination of Dodge and Singh would not work as Dodge could not operate at temperatures of 800-1000° C and Singh could not operate at temperatures of 80-100° C. Inability to operate would be further hindered by the fact that the two fuel cells taught by Dodge and Singh use different fuel sources.

Isenberg is cited for the proposition that it teaches a “cathode layer of discontinuous length along the assembly to provide a plurality of longitudinally spaced cathode portions.” Office Action at page 9. However, Isenberg does not teach a tubular solid oxide fuel cell.

Further, Applicant points out that Isenberg is incompatible with Dodge. Dodge discloses a PEM fuel cell that operates at temperatures of 80-100° C. In contrast, Isenberg is related to a solid electrolyte fuel cell that operate at above 700° C. Thus, Applicant submits that Isenberg does not rectify the deficiencies of Dodge and Singh and, further, is incompatible with Dodge as neither apparatus would be functional at the operating temperature of the other. The rejection being therefore overcome, withdrawal is respectfully requested.

Claims 28-29 are rejected under 35 USC § 103(a) as being unpatentable over Dodge (WO 96/04690) in view of Singh et al. (U.S. Patent No. 4,894,297), as applied to Claims 1-8, 17-21, 51-57 above, and in further view of Sammes (WO 99/17390).

This rejection is overcome, at least, for the following reasons.

Sammes Does Not Remedy The Defects Of Dodge And Singh

The combination of Dodge and Singh is inoperable. As discussed above, Dodge does not disclose a solid oxide fuel cell. Dodge is incompatible with Singh. The combination of Dodge and Singh would not work as Dodge could not operate at temperatures of 800-1000° C and Singh could not operate at 80-100° C. Inability to operate would be further hindered by the fact that the two fuel cells taught by Dodge and Singh use different fuel sources.

Sammes does not cure the defects of Dodge and Singh. Sammes discloses a solid oxide fuel cell. As discussed above, solid oxide fuel cells require operation at temperatures of about 700-1000° C. Sammes requires operation at temperatures of between 600-1000° C. Therefore, Sammes not only does not cure the defects of Dodge, the combination of Sammes and Dodge is inoperable because Dodge requires operation at temperatures of 80-100° C. The combination simply would not work. The rejection being thus overcome, withdrawal is respectfully requested.

Claims 30-32 are rejected under 35 USC § 103(a) as being unpatentable over Dodge (WO 96/04690) in view of Singh et al. (U.S. Patent No. 4,894,297), as applied to claims 1-8, 17-21, 51-57 above, and in further view of Goodenough (U.S. Patent No. 6,004,688).

This rejection is overcome, at least, for the following reasons.

Goodenough Does Not Cure The Defects Of Dodge And Sammes

The combination of Dodge and Singh is inoperable. As discussed above, Dodge does not disclose a solid oxide fuel cell. Dodge is incompatible with Singh. The combination of Dodge and Singh would not work as Dodge could not operate at temperatures of 800-1000° C and Singh could not operate at temperatures of 80-100° C. Inability to operate would be further hindered by the fact that the two fuel cells taught by Dodge and Singh use different fuel sources.

Goodenough discloses a planar, solid oxide fuel cell and perovskite lanthanum gallate electrolyte. Goodenough discloses an “improved” electrolyte that has the highest conductivity at 800° C and 700° C, respectively. Goodenough at col. 2, lines 50-51. Dodge requires operation at 80-100° C. Therefore, Goodenough does not teach a tubular solid oxide fuel cell and is incompatible with Dodge. Dodge further does not teach a solid oxide fuel cell at all and is incompatible with Goodenough. The rejection is therefore overcome and should be withdrawn. Applicant respectfully requests same.

Conclusion

In view of the foregoing, it is respectfully submitted that the claims of record are allowable and that the application should be passed to issue. Should the Examiner believe that the application is not in a condition for allowance and that a telephone interview would help further prosecution of this case, the Examiner is requested to contact the undersigned attorney at the phone number below.

Respectfully submitted,

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Date: Oct. 13, 2008

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**US Army Corps
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Ceramic Anodes for Corrosion Prevention

Technology

The ceramic-coated ("durable") anode is a cost-effective method for combating corrosion in the high-volume, low-cost materials such as those used in military and civil works applications. The ceramic-coated anode is a much improved alternative to the traditional silicon-iron and graphite impressed current anodes. The advantages of ceramic anodes are their: (1) light weight, (2) dimensional stability (i.e., they do not change shape.), and (3) long life. Cathodic protection designs using ceramic anodes are available for lock and dam gates, elevated water storage tanks, buried pipe, buried storage tank, and also in systems using electro-osmotic pulse (EOP) technology (an emerging technology that mitigates "wet basement" problems without the cost of excavation).

Problem

Corrosion of metallic structures buried in soil or immersed in water can be stopped by using cathodic protection devices that involve applying a small electrical current from an outside source to the corroding structure. The current is applied through an anode that eventually is consumed by the electrical current. The anode is the positive terminal in the corrosion battery and the structure is the negative terminal, as in a flashlight battery where the center of the battery is positive and the casing is negative. The silicon-iron and graphite materials used over the past 30 years in cathodic-protection anodes are brittle and have consumption rates of approximately 1 pound per ampere year. Consequently, structures required large anodes, which were vulnerable to debris and ice damage and field installation problems, which in turn caused numerous electrical shorts in the system.

Expected Cost To Implement

The cost to implement ceramic anode technology will vary depending on the number, size, and type of anode to be used; individual user requirements; and the size and scope of the application. Questions regarding application cost for a specific project should be referred to APS Materials, Inc. (the exclusively licensed Distribution Source listed below).

Benefits/Savings

The consumption rate of conducting ceramic materials such as mixed metal oxides is 500 times less than the silicon-iron and graphite anodes. This resulted in a smaller, (up to 150 times) lighter anode with the same life span. The ceramic coated anode also has a factory fabricated and tested redundant electrical connection. This eliminates installation problems associated with silicon-iron and graphite anodes and results in positive electrical isolation between the anode and the structure. In addition, the ceramic-coated anode is resistant to mechanical damage caused by floating debris due to the tough anode substrate and protective design fea-



Ceramic anodes are successfully applied to Civil Works dam projects.

tures. These factors significantly increase the cathodic protection system reliability from an average of 20 percent to a potential 90 percent.

Status	Technology transfer of ceramic anode technology is complete. The use of ceramic anodes is prescribed in Corps of Engineers Engineer Manual (EM) 1110-2-2704. The ceramic coated anode won the 1985 IR-100 Award, presented by Research and Development Magazine to recognize the 100 most significant products. The ceramic-coated anode also won the Army Research and Development Achievement Award in 1984, the Army Science Conference Award for Outstanding Achievement in 1984, and the Technology Transfer Excellence Award in 1991 from the Federal Laboratory Consortium.
ERDC POC	<p>Dr. Ashok Kumar, Metallurgist, Construction Engineering Research Laboratory (CERL), PO Box 9005, Champaign, IL, 61826-9005. Phone: 217-373-7235, e-mail: Ashok.Kumar@usace.army.mil</p> <p>Vincent F Hock, Metallurgist, CERL, PO Box 9005, Champaign, IL, 61826-9005. Phone: 217-373-6753, e-mail: Vincent.F.Hock@erdc.usace.army.mil</p>
Documentation	<p>Engineer Manual (EM) 1110-2-2704, <i>Cathodic Protection Systems for Civil Works Structures (Department of the Army [DA], Washington, DC, 1 January 1999)</i>, available through URL: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em1110-2-2704/entire.pdf</p> <p>Engineer Technical Letter, ETL-1110-9-10, <i>Engineering and Design – Cathodic Protection System Using Ceramic Anodes</i>, 5 January 1991, available through URL: http://www.usace.army.mil/inet/usace-docs/eng-tech-ltrs/etl1110-9-10/toc.html</p> <p>Vincent F. Hock, Richard Ruzga, and Ashok Kumar, Technical Report (TR) FM-95/05, <i>Field Evaluation of Cathodic Protection Systems Using Ceramic-Coated Anodes for Lock and Dam Gates</i> (CERL, September 1994).</p>
Distribution Source	The exclusive license for the Construction Engineering Research Laboratory (CERL) ceramic anode patent was awarded to APS Materials, Inc., of Dayton, OH, in May 1984. APS Materials ("CerAnode Division") manufactures, markets, and provides user support for the ceramic-coated anode. Further contact information is available through URL: http://www.apsmaterials.com/common/corp_main.htm http://www.apsmaterials.com/common/corp_main.htm

Appendix II

Ceramic engineering

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From Wikipedia, the free encyclopedia

Ceramic Engineering is the technology of manufacturing and usage of ceramic materials. Many engineering applications benefit from ceramics characteristics as a material. The characteristics of ceramics have garnered attention from engineers across the world, including those in the fields: Electrical Engineering, Materials Engineering, Chemical Engineering, Mechanical Engineering, and many others. Highly regarded for being resistant to heat, ceramics can be used for many demanding tasks that other materials like Metal and Polymers can not.

Traditional ceramic raw materials include clay minerals such as kaolinite, more recent materials include aluminium oxide, more commonly known as alumina. The modern ceramic materials, which are classified as advanced ceramics, include silicon carbide and tungsten carbide. Both are valued for their abrasion resistance, and hence find use in applications such as the wear plates of crushing equipment in mining operations. Advanced ceramics are also used in the medicine, electrical and electronics industries.

Ceramic Engineers are found in a wide variety of manufacturing, research and educational fields. These include mining, aerospace, medicine, refinery, food industry, chemical industry, packaging science, electronics, industrial electricity, and transmission electricity.

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The Ceramic Process

A general definition of a ceramic material could be: A ceramic is any inorganic crystalline oxide material. It is solid and inert. Ceramic materials are brittle, hard, strong in compression, weak in shearing and tension. They withstand chemical erosion that occur in an acidic or caustic environment. In many cases withstanding erosion from the acid and bases applied to it. Ceramics generally can withstand very high temperatures such as temperatures that range from 1,000°C to 1,600°C (1,800°F to 3,000°F). Exceptions include inorganic materials that do not have oxygen such silicon carbide. Glass by definition is not a ceramic because it is an amorphous solid (non-crystalline). However, glass involves several steps of the ceramic process and its mechanical properties behave similarly to ceramic materials.

The ceramic process generally follows this flow.

Milling→ Batching→ Mixing→ Forming→ Drying→ Firing→ Assembly→

Milling is the process by which materials are reduced from a larger size to a smaller size. Milling may involve breaking up cemented material, thus the individual particle retain their shape or pulverization which involves grinding the particles themselves to a smaller size. Pulverization is actually fracturing the grains and breaking them down.

Generally milling is done through mechanical means. The means include attrition which is particle to particle collision that results in agglomerate break up or particle shearing. Compression which is applying compressive forces that result in break-up or fracturing. Another means is impact which involves a milling media -or the particles themselves- that cause break up or fracturing

Examples of equipment that achieve attrition milling is a planetary mill or an wet attrition mill, also called wet scrubber. A wet scrubber is a machine that has paddles in water turning in opposite direction causing two vortexes turning into each other. The material in the vortex collide and break up.

Equipment that achieve compression milling include a jaw crusher, roller crusher, and cone crushers.

Finally impact mills may include a ball mill with media that tumble and fracture material. Shaft impactors cause particle to particle attrition and compression which achieve size reduction.

Batching is the process of weighing the oxides according to recipes, and preparing them for mixing and drying.

Mixing occurs after batching and involve a variety of equipment such as dry mixing ribbon mixers (a type of cement mixer), Mueller mixers, and pug mills. Wet mixing generally involve the same equipment.

Forming is making the mixed material into shapes, ranging from toilet bowls to spark plug insulators. Forming can involve: 1) Extrusion, such as extruding "slugs" to make bricks 2) Pressing to make shaped parts. 3) Slip casting, as in making toilet bowls, wash basins and ornamentals like ceramic statues. Forming produces a "green" part, ready for drying. Green parts are soft, pliable, and over time will lose shape. Handling the green product will change its shape. For example, a green brick can be "squeezed", and after squeezing it will stay that way.

Drying is removing the water or binder from the formed material. Spray drying is widely used to prepare powder for pressing operations. Other dryers are tunnel dryers and periodic dryers. Controlled heat is applied in this two-stage process. First, heat removes water. This step needs careful control, as rapid heating causes cracks and surface defects. The dried part is smaller than the green part, and is brittle, necessitating careful handling, since a small impact will cause crumbling and breaking.

Firing is where the dried parts pass through a controlled heating process, and the oxides are chemically changed to cause sintering and bonding. The fired part will be smaller than the dried part.

Assembly This process is for parts that require additional subassembly parts. In the case of a spark plug, the electrode is put into the insulator. This step does not apply to all ceramic products.

Ceramics Applications in Engineering

Ceramics can be used in many technological industries. One application are the ceramic tiles on NASA's Space Shuttle, used to protect it and the future supersonic space planes from the searing heat of reentry into the earth's atmosphere. They are also used widely in electronics and optics. In addition to the applications listed here, ceramics are also used as a coating in various engineering cases. An example would be a ceramic bearing coating over a titanium frame used for an airplane. Recently the field has come to include the studies of single crystals or glass fibers, in addition to traditional Polycrystalline materials, and the applications of these have been overlapping and changing rapidly.

Aerospace:

- Engines; Shielding a hot running airplane engine from damaging other components.
- Airframes; Used as a high-stress, high-temp and lightweight bearing and structural component.
- Missile nose-cones; Shielding the missile internals from heat.
- Space Shuttle tiles
- Rocket Nozzles; Withstands and focuses the exhaust of the rocket booster.

Biomedical:

- Artificial bone; Dentistry applications, teeth.
- Biodegradable splints; Reinforcing bones recovering from osteoporosis
- Implant material

Electronics and Electrical Industry:

- Capacitors
- Integrated Circuit packages
- Transducers

- Insulators

Optical/Photonic:

- Optical fibers; Glass fibers for super fast data transmission.
- Switches
- Laser amplifiers
- Lenses

History of Ceramics in Engineering

Ceramics Engineering, like many sciences, evolved from a different discipline by today's standards. Materials Engineering is grouped with Ceramics Engineering to this day. Universities with ceramics programs include a curriculum saturated with materials engineering classes.

The modern day ceramic engineer may find themselves in a variety of industries. Similar to other disciplines a ceramic engineer may find themselves in mining and mineral processing, pharmaceuticals, foods, and chemical operations.

Abraham Darby first used coke in 1709 in Shropshire, England, to improve the yield of a smelting process. Coke is now widely used to produce carbide ceramics. Potter Josiah Wedgwood opened the first modern ceramics factory in Stoke-on-Trent, England, in 1759. Austrian chemist Karl Bayer, working for the textile industry in Russia, developed a process to separate alumina from bauxite ore in 1888. The Bayer process is still used to purify alumina for the ceramic and aluminum industries. Brothers Pierre and Jacques Curie discovered piezoelectricity in Rochelle salt circa 1880. Piezoelectricity is one of the key properties of electroceramics. E.G. Acheson heated a mixture of coke and clay in 1893, and invented carborundum, or synthetic silicon carbide. Henri Moissan also synthesized SiC and tungsten carbide in his electric arc furnace in Paris about the same time as Acheson. Karl Schröter used liquid-phase sintering to bond or "cement" Moissan's tungsten carbide particles with cobalt in 1923 in Germany. Cemented (metal-bonded) carbide edges greatly increase the durability of hardened steel cutting tools. W.H. Nernst developed cubic-stabilized zirconia (CSZ) in the 1920s in Berlin. CSZ is used as an oxygen sensor in exhaust systems. W.D. Kingery and others in the 1950s developed partially-stabilized zirconia (PSZ), greatly increasing its toughness. PSZ is used to make cutlery and other tools. Lead zirconate titanate (PZT) was developed at the United States National Bureau of Standards in 1954. PZT is used as an ultrasonic transducer, as its piezoelectric properties greatly exceed those of Rochelle salt.^[1]

The first ceramic engineering course and department in the United States were established by Edward Orton, Jr., a professor of geology and mining engineering, at the Ohio State University in 1894. Orton and eight other refractory professionals founded the American Ceramic Society (ACerS) at the 1898 National Brick Manufacturers' Association convention in Pittsburgh. Orton was the first ACerS General Secretary, and his office at OSU served as the society headquarters in the beginning. Charles F. Binns established the New York State School of Clay-Working and Ceramics, now Alfred University, in 1900. Binns was the third ACerS president, and Orton the 32nd.^[2] The Ceramic Society of Japan was founded in 1891 in Tokyo. *Deutschen Keramischen Gesellschaft*, the ceramic society of Germany, was founded in Berlin in 1919.

The military requirements of World War II (1939-1945) encouraged developments, which created a need for high-performance materials and helped speed the development of ceramic science and engineering. Throughout the 1960s and 1970's, new types of ceramics were developed in response to advances in atomic energy, electronics, communications, and space travel. The discovery of ceramic superconductors in 1986 has spurred intense research to develop superconducting ceramic parts for electronic devices, electric motors, and transportation equipment.

Preceding the spark of the ceramic industry in the late 19th century, there was the study of materials closely associated with chemistry. Since Ceramics are comprised of a crystalline structure, the knowledge of crystal formation and the strengths involved was important in the development of ceramics as a standalone scientific field.

Present Day Ceramics Engineering

Now a multi-billion dollar a year industry, ceramics engineering and research has established itself as an important field of science. Applications continue to expand as researchers develop new kinds of ceramics to serve different purposes. An incredible number of ceramics engineering products have made their way into modern life. The largest producers of engineered ceramics--and largest employers of ceramic engineers--include AVX, CeramTec, CoorsTek, Corning, EDO, Kohler, Kyocera, Morgan Crucible, Murata, Saint-Gobain and 3M.

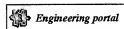
Education

Many educational institutions in the United States offer degrees in this field, examples being the New York State College of Ceramics located at Alfred University, and Rutgers University, and there are several in other countries. Some of these institutions are planning to change the names of their disciplines to Materials science, "Materials engineering" or Materials Science and Engineering (MS&E). Clemson University and the Missouri University of Science and Technology^[3] offer Ceramic Engineering Major & Materials Minor.

See also

- Materials Engineering
- Mechanical Engineering
- Chemical Engineering
- Ceramography

Further reading



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- ↑ *The American Ceramic Society: 100 Years*, American Ceramic Society, 1998, p 169-173, ISBN 1-888903-04-X.
- ↑ *Brow, Richard K.. "Ceramic Engineering at the University of Missouri-Rolla" (PDF). Archived from the original on 2003-06-25. Retrieved on 2007-10-07.

External links

- The American Ceramic Society
- Ceramic Engineering Companies

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Categories: Materials science | Ceramics | Ceramic materials

Hidden categories: Articles with limited geographic scope | USA-centric | Pages needing expert attention | Wikipedia articles needing factual verification since May 2008

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Appendix III

Ceramic

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From Wikipedia, the free encyclopedia

The word **ceramic** is derived from the Greek word κεραμικός (*keramikos*). The term covers inorganic non-metallic materials which are formed by the action of heat. Up until the 1950s or so, the most important of these were the traditional clays, made into pottery, bricks, tiles and the like, along with cements and glass. Clay-based ceramics are described in the article on pottery. A composite material of ceramic and metal is known as cermet. The word *ceramic* can be an adjective, and can also be used as a noun to refer to a ceramic material, or a product of ceramic manufacture. *Ceramics* may also be used as a singular noun referring to the art of making things out of ceramic materials. The technology of manufacturing and usage of ceramic materials is part of the field of ceramic engineering.



Fixed Partial Denture, or "Bridge"

Many ceramic materials are hard, porous, and brittle. The study and development of ceramics includes methods to mitigate problems associated with these characteristics, and to accentuate the strengths of the materials as well as to investigate novel applications.

The American Society for Testing and Materials (ASTM) defines a ceramic article as *"an article having a glazed or unglazed body of crystalline or partly crystalline structure, or of glass, which body is produced from essentially inorganic, non-metallic substances and either is formed from a molten mass which solidifies on cooling, or is formed and simultaneously or subsequently matured by the action of the heat."*^[1]

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- 1 Types of ceramic materials
 - 1.1 Examples of whiteware ceramics
 - 1.2 Classification of technical ceramics
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- 2 Properties of ceramics
 - 2.1 Mechanical properties
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 - 2.2.1 Semiconductors
 - 2.2.2 Superconductivity
 - 2.2.3 Ferroelectricity and superset
 - 2.2.4 Positive thermal coefficient
- 3 Classification of ceramics
 - 3.1 In situ manufacturing
 - 3.2 Sintering-based methods
- 4 Other applications of ceramics
- 5 See also
- 6 References
- 7 External links

Types of ceramic materials

For convenience ceramic products are usually divided into four sectors, and these are shown below with some examples:

- *Structural*, including bricks, pipes, floor and roof tiles
- *Refractories*, such as kiln linings, gas fire radiants, steel and glass making crucibles
- *Whitewares*, including tableware, wall tiles, decorative art objects and sanitary ware
- *Technical*, is also known as Engineering, Advanced, Special, and in Japan, Fine Ceramics. Such items include tiles used in the Space Shuttle program, gas burner nozzles, ballistic protection, nuclear fuel uranium oxide pellets, bio-medical implants, jet engine turbine blades, and missile nose cones. Frequently the raw materials do not include clays.

Examples of whiteware ceramics

- Bone china
- Earthenware, which is often made from clay, quartz and feldspar.

- Porcelain, which are often made from kaolin
- Stoneware

Classification of technical ceramics

Technical ceramics can also be classified into three distinct material categories:

- Oxides: Alumina, zirconia
- Non-oxides: Carbides, borides, nitrides, silicides
- Composites: Particulate reinforced, combinations of oxides and non-oxides.

Each one of these classes can develop unique material properties

Examples of technical ceramics

- Barium titanate (often mixed with strontium titanate) displays ferroelectricity, meaning that its mechanical, electrical, and thermal responses are coupled to one another and also history-dependent. It is widely used in electromechanical transducers, ceramic capacitors, and data storage elements. Grain boundary conditions can create PTC effects in heating elements.
- Bismuth strontium calcium copper oxide, a high-temperature superconductor
- Boron nitride is structurally isoelectronic to carbon and takes on similar physical forms: a graphite-like one used as a lubricant, and a diamond-like one used as an abrasive.
- Ferrite (Fe_3O_4), which is ferrimagnetic and is used in the magnetic cores of electrical transformers and magnetic core memory.
- Lead zirconate titanate is another ferroelectric material.
- Magnesium diboride (MgB_2), which is an unconventional superconductor.
- Sialons / Silicon Aluminium Oxynitrides, high strength, high thermal shock / chemical / wear resistance, low density ceramics used in non-ferrous molten metal handling, weld pins and the chemical industry.
- Silicon carbide (SiC), which is used as a susceptor in microwave furnaces, a commonly used abrasive, and as a refractory material.
- Silicon nitride (Si_3N_4), which is used as an abrasive powder.
- Steatite (magnesium silicates) is used as an electrical insulator.
- Titanium Carbide Used in space shuttle re-entry shields and scratchproof watches.
- Uranium oxide (UO_2), used as fuel in nuclear reactors.
- Yttrium barium copper oxide ($\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$), another high temperature superconductor.
- Zinc oxide (ZnO), which is a semiconductor, and used in the construction of varistors.
- Zirconium dioxide (zirconia), which in pure form undergoes many phase changes between room temperature and practical sintering temperatures, can be chemically "stabilized" in several different forms. Its high oxygen ion conductivity recommends it for use in fuel cells. In another variant, metastable structures can impart transformation toughening for mechanical applications; most ceramic knife blades are made of this material.

Properties of ceramics

Mechanical properties

Ceramic materials are usually ionic or covalent bonded materials, and can be crystalline or amorphous. A material held together by either type of bond will tend to fracture before any plastic deformation takes place, which results in poor toughness in these materials. Additionally, because these materials tend to be porous, the pores and other microscopic imperfections act as stress concentrators, decreasing the toughness further, and reducing the tensile strength. These combine to give catastrophic failures, as opposed to the normally much more gentle failure modes of metals.

These materials do show plastic deformation. However, due to the rigid structure of the crystalline materials, there are very few available slip systems for dislocations to move, and so they deform very slowly. With the non-crystalline (glassy) materials, viscous flow is the dominant source of plastic deformation, and is also very slow. It is therefore neglected in many applications of ceramic materials.

Electrical properties

Semiconductors

There are a number of ceramics that are semiconductors. Most of these are transition metal oxides that are II-VI semiconductors,

such as zinc oxide.

While there is talk of making blue LEDs from zinc oxide, ceramicists are most interested in the electrical properties that show grain boundary effects.

One of the most widely used of these is the varistor. These are devices that exhibit the property that resistance drops sharply at a certain threshold voltage. Once the voltage across the device reaches the threshold, there is a breakdown of the electrical structure in the vicinity of the grain boundaries, which results in its electrical resistance dropping from several megohms down to a few hundred ohms. The major advantage of these is that they can dissipate a lot of energy, and they self reset — after the voltage across the device drops below the threshold, its resistance returns to being high.

This makes them ideal for surge-protection applications. As there is control over the threshold voltage and energy tolerance, they find use in all sorts of applications. The best demonstration of their ability can be found in electrical substations, where they are employed to protect the infrastructure from lightning strikes. They have rapid response, are low maintenance, and do not appreciably degrade from use, making them virtually ideal devices for this application.

Semiconducting ceramics are also employed as gas sensors. When various gases are passed over a polycrystalline ceramic, its electrical resistance changes. With tuning to the possible gas mixtures, very inexpensive devices can be produced.

Superconductivity

Under some conditions, such as extremely low temperature, some ceramics exhibit high temperature superconductivity. The exact reason for this is not known, but there are two major families of superconducting ceramics .

Ferroelectricity and supersets

Piezoelectricity, a link between electrical and mechanical response, is exhibited by a large number of ceramic materials, including the quartz used to measure time in watches and other electronics. Such devices use both properties of piezoelectrics, using electricity to produce a mechanical motion (powering the device) and then using this mechanical motion to produce electricity (generating a signal). The unit of time measured is the natural interval required for electricity to be converted into mechanical energy and back again.

The piezoelectric effect is generally stronger in materials that also exhibit pyroelectricity, and all pyroelectric materials are also piezoelectric. These materials can be used to inter convert between thermal, mechanical, and/or electrical energy; for instance, after synthesis in a furnace, a pyroelectric crystal allowed to cool under no applied stress generally builds up a static charge of thousands of volts. Such materials are used in motion sensors, where the tiny rise in temperature from a warm body entering the room is enough to produce a measurable voltage in the crystal.

In turn, pyroelectricity is seen most strongly in materials which also display the ferroelectric effect, in which a stable electric dipole can be oriented or reversed by applying an electrostatic field. Pyroelectricity is also a necessary consequence of ferroelectricity. This can be used to store information in ferroelectric capacitors, elements of ferroelectric RAM.

The most common such materials are lead zirconate titanate and barium titanate. Aside from the uses mentioned above, their strong piezoelectric response is exploited in the design of high-frequency loudspeakers, transducers for sonar, and actuators for atomic force and scanning tunneling microscopes.

Positive thermal coefficient

Increases in temperature can cause grain boundaries to suddenly become insulating in some semiconducting ceramic materials, mostly mixtures of heavy metal titanates. The critical transition temperature can be adjusted over a wide range by variations in chemistry. In such materials, current will pass through the material until joule heating brings it to the transition temperature, at which point the circuit will be broken and current flow will cease. Such ceramics are used as self-controlled heating elements in, for example, the rear-window defrost circuits of automobiles.

At the transition temperature, the material's dielectric response becomes theoretically infinite. While a lack of temperature control would rule out any practical use of the material near its critical temperature, the dielectric effect remains exceptionally strong even at much higher temperatures. Titanates with critical temperatures far below room temperature have become synonymous with "ceramic" in the context of ceramic capacitors for just this reason.

Classification of ceramics

Non-crystalline ceramics: Non-crystalline ceramics, being glasses, tend to be formed from melts. The glass is shaped when either fully molten, by casting, or when in a state of toffee-like viscosity, by methods such as blowing to a mold. If later heat-treatments cause this class to become partly crystalline, the resulting material is known as a glass-ceramic.

Crystalline ceramics: Crystalline ceramic materials are not amenable to a great range of processing. Methods for dealing with them tend to fall into one of two categories - either make the ceramic in the desired shape, by reaction in situ, or by "forming" powders into the desired shape, and then sintering to form a solid body. Ceramic forming techniques include shaping by hand (sometimes including a rotation process called "throwing"), slip casting, tape casting (used for making very thin ceramic capacitors, etc.), injection molding, dry pressing, and other variations. (See also Ceramic forming techniques. Details of these processes are described in the two books listed below.) A few methods use a hybrid between the two approaches.

In situ manufacturing

The most common use of this method is in the production of cement and concrete. Here, the dehydrated powders are mixed with water. This starts hydration reactions, which result in long, interlocking crystals forming around the aggregates. Over time, these result in a solid ceramic.

The biggest problem with this method is that most reactions are so fast that good mixing is not possible, which tends to prevent large-scale construction. However, small-scale systems can be made by deposition techniques, where the various materials are introduced above a substrate, and react and form the ceramic on the substrate. This borrows techniques from the semiconductor industry, such as chemical vapour deposition, and is very useful for coatings.

These tend to produce very dense ceramics, but do so slowly.

Sintering-based methods

The principles of sintering-based methods is simple. Once a roughly held together object (called a "green body") is made, it is baked in a kiln, where diffusion processes cause the green body to shrink. The pores in the object close up, resulting in a denser, stronger product. The firing is done at a temperature below the melting point of the ceramic. There is virtually always some porosity left, but the real advantage of this method is that the green body can be produced in any way imaginable, and still be sintered. This makes it a very versatile route.

There are thousands of possible refinements of this process. Some of the most common involve pressing the green body to give the densification a head start and reduce the sintering time needed. Sometimes organic binders such as polyvinyl alcohol are added to hold the green body together; these burn out during the firing (at 200–350°C). Sometimes organic lubricants are added during pressing to increase densification. It is not uncommon to combine these, and add binders and lubricants to a powder, then press. (The formulation of these organic chemical additives is an art in itself. This is particularly important in the manufacture of high performance ceramics such as those used by the billions for electronics, in capacitors, inductors, sensors, etc. The specialized formulations most commonly used in electronics are detailed in the book "Tape Casting," by R.E. Mistler, et al., Amer. Ceramic Soc. [Westerville, Ohio], 2000.) A comprehensive book on the subject, for mechanical as well as electronics applications, is "Organic Additives and Ceramic Processing," by D. J. Shanefield, Kluwer Publishers [Boston], 1996.

A slurry can be used in place of a powder, and then cast into a desired shape, dried and then sintered. Indeed, traditional pottery is done with this type of method, using a plastic mixture worked with the hands.

If a mixture of different materials is used together in a ceramic, the sintering temperature is sometimes above the melting point of one minor component - a *liquid phase* sintering. This results in shorter sintering times compared to solid state sintering.

Other applications of ceramics

- Ceramics are used in the manufacture of knives. The blade of the ceramic knife will stay sharp for much longer than that of a steel knife, although it is more brittle and can be snapped by dropping it on a hard surface.
- Ceramics such as alumina and boron carbide have been used in ballistic armored vests to repel large-caliber rifle fire. Such plates are known commonly as small-arms protective inserts (SAPI). Similar material is used to protect cockpits of some military airplanes, because of the low weight of the material.
- Ceramic balls can be used to replace steel in ball bearings. Their higher hardness means that they are much less susceptible to wear and can offer more than triple lifetimes. They also deform less under load meaning they have less contact with the

bearing retainer walls and can roll faster. In very high speed applications, heat from friction during rolling can cause problems for metal bearings; problems which are reduced by the use of ceramics. Ceramics are also more chemically resistant and can be used in wet environments where steel bearings would rust. The major drawback to using ceramics is a significantly higher cost. In many cases their electrically insulating properties may also be valuable in bearings.

- In the early 1980s, Toyota researched production of an adiabatic ceramic engine which can run at a temperature of over 6000 °F (3300 °C). Ceramic engines do not require a cooling system and hence allow a major weight reduction and therefore greater fuel efficiency. Fuel efficiency of the engine is also higher at high temperature, as shown by Carnot's theorem. In a conventional metallic engine, much of the energy released from the fuel must be dissipated as waste heat in order to prevent a meltdown of the metallic parts. Despite all of these desirable properties, such engines are not in production because the manufacturing of ceramic parts in the requisite precision and durability is difficult. Imperfection in the ceramic leads to cracks, which can lead to potentially dangerous equipment failure. Such engines are possible in laboratory settings, but mass-production is not feasible with current technology.
- Work is being done in developing ceramic parts for gas turbine engines. Currently, even blades made of advanced metal alloys used in the engines' hot section require cooling and careful limiting of operating temperatures. Turbine engines made with ceramics could operate more efficiently, giving aircraft greater range and payload for a set amount of fuel.
- Recently, there have been advances in ceramics which include bio-ceramics, such as dental implants and synthetic bones. Hydroxyapatite, the natural mineral component of bone, has been made synthetically from a number of biological and chemical sources and can be formed into ceramic materials. Orthopedic implants made from these materials bond readily to bone and other tissues in the body without rejection or inflammatory reactions. Because of this, they are of great interest for gene delivery and tissue engineering scaffolds. Most hydroxy apatite ceramics are very porous and lack mechanical strength and are used to coat metal orthopedic devices to aid in forming a bond to bone or as bone fillers. They are also used as fillers for orthopedic plastic screws to aid in reducing the inflammation and increase absorption of these plastic materials. Work is being done to make strong, fully dense nano crystalline hydroxyapatite ceramic materials for orthopedic weight bearing devices, replacing foreign metal and plastic orthopedic materials with a synthetic, but naturally occurring, bone mineral. Ultimately these ceramic materials may be used as bone replacements or with the incorporation of protein collagens, synthetic bones.
- High-tech ceramic is used in watchmaking for producing watch cases. The material is valued by watchmakers for its light weight, scratch-resistance, durability and smooth touch. IWC is one of the brands that initiated the use of ceramic in watchmaking. The case of the IWC 2007 Top Gun edition of the Pilot's Watch Double chronograph is crafted in high-tech black ceramic.^[2]

See also

- Ceramics (art)
- Ceramic forming techniques
- Glass-ceramic-to-metal seals
- Porcelain
- Pottery
- Three point flexural test
- Phase Equilibria Diagrams database

References

- ¹ ^ Ceramic Tile and Stone Standards
- ² ^ Ceramic in Watchmaking

External links

- Advanced Ceramics – The Evolution, Classification, Properties, Production, Firing, Finishing and Design of Advanced Ceramics
- How pottery is made
- How sanitaryware is made
- World renowned ceramics collections at Stoke-on-Trent Museum Click on **Quick Links** in the right-hand column to view examples.
- The Gardiner Museum - The only museum in Canada entirely devoted to ceramics.
- Introduction, Scientific Principles, Properties and Processing of Ceramics
- The American Ceramic Society The American Ceramic Society

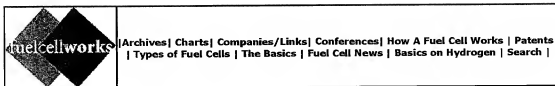
- Worldwide Ceramics Directory

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Categories: Ceramic materials | Dielectrics

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Appendix IV



Types Of Fuel Cells

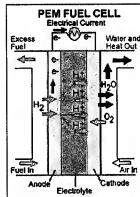
Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications. A few of the most promising types include

- Polymer Electrolyte Membrane (PEM)
- Phosphoric Acid
- Direct Methanol
- Alkaline
- Molten Carbonate
- Solid Oxide
- Regenerative (Reversible)
- Fuel Cell Comparisons
- Electrochemical reactions of the Fuel Cell types

Polymer Electrolyte Membrane

Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or onboard reformers.

Polymer electrolyte membrane fuel cells operate at relatively low temperatures, around 80°C (176°F). Low temperature operation allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding to system cost. The platinum catalyst is also extremely sensitive to CO poisoning, making it necessary to employ an additional reactor to reduce CO in the fuel gas if the hydrogen is derived from an alcohol or hydrocarbon fuel. This also adds cost. Developers are currently exploring platinum/ruthenium catalysts that are more resistant to CO.



PEM fuel cells are used primarily for transportation applications and some stationary applications. Due to their fast startup time, low sensitivity to orientation, and favorable power-to-weight ratio, PEM fuel cells are particularly suitable for use in passenger vehicles, such as cars and buses.

A significant barrier to using these fuel cells in vehicles is hydrogen storage. Most fuel cell vehicles (FCVs) powered by pure hydrogen must store the hydrogen onboard as a compressed gas in pressurized tanks. Due to the low energy density of hydrogen, it is difficult to store enough hydrogen onboard to allow vehicles to travel the same distance as gasoline-powered vehicles before refueling, typically 300-400 miles. Higher-density liquid fuels such as methanol, ethanol, natural gas, liquefied petroleum gas, and gasoline can be used for fuel, but the vehicles must have an onboard fuel processor to reform the methanol to hydrogen. This increases costs and maintenance requirements. The reformer also releases carbon dioxide (a greenhouse gas), though less than that emitted from current gasoline-powered engines.

Phosphoric Acid

Phosphoric acid fuel cells use liquid phosphoric acid as an electrolyte—the acid is contained in a Teflon-bonded silicon carbide matrix—and



porous carbon electrodes containing a platinum catalyst. The chemical reactions that take place in the cell are shown in the diagram to the right.

The phosphoric acid fuel cell (PAFC) is considered the "first generation" of modern fuel cells. It is one of the most mature cell types and the first to be used commercially, with over 200 units currently in use. This type of fuel cell is typically used for stationary power generation, but some PAFCs have been used to power large vehicles such as city buses.

PAFCs are more tolerant of impurities in the reformat than PEM cells, which are easily "poisoned" by carbon monoxide—carbon monoxide binds to the platinum catalyst at the anode, decreasing the fuel cell's efficiency. They are 85 percent efficient when used for the co-generation of electricity and heat, but less efficient at generating electricity alone (37 to 42 percent). This is only slightly more efficient than combustion-based power plants, which typically operate at 33 to 35 percent efficiency. PAFCs are also less powerful than other fuel cells, given the same weight and volume. As a result, these fuel cells are typically large and heavy. PAFCs are also expensive. Like PEM fuel cells, PAFCs require an expensive platinum catalyst, which raises the cost of the fuel cell. A typical phosphoric acid fuel cell costs between \$4,000 and \$4,500 per kilowatt to operate.

Direct Methanol

Most fuel cells are powered by hydrogen, which can be fed to the fuel cell system directly or can be generated within the fuel cell system by reforming hydrogen-rich fuels such as methanol, ethanol, and hydrocarbon fuels. Direct methanol fuel cells (DMFCs), however, are powered by pure methanol, which is mixed with steam and fed directly to the fuel cell anode.

Direct methanol fuel cells do not have many of the fuel storage problems typical of some fuel cells since methanol has a higher energy density than hydrogen—though less than gasoline or diesel fuel. Methanol is also easier to transport and supply to the public using our current infrastructure since it is a liquid, like gasoline.

Direct methanol fuel cell technology is relatively new compared to that of fuel cells powered by pure hydrogen, and research and development are roughly 3–4 years behind that of other fuel cell types.

Alkaline

Alkaline fuel cells (AFCs) were one of the first fuel cell technologies developed, and they were the first type widely used in the U.S. space program to produce electrical energy and water onboard spacecraft. These fuel cells use a solution of potassium hydroxide in water as the electrolyte and can use a variety of non-precious metals as a catalyst at the anode and cathode. High-temperature AFCs operate at temperatures between 100°C and 250°C (212°F and 482°F). However, more recent AFC designs operate at lower temperatures of roughly 23°C to 70°C (74°F to 158°F).

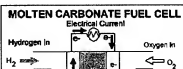
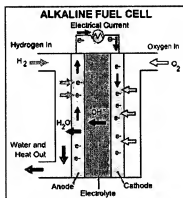
AFCs are high-performance fuel cells due to the rate at which chemical reactions take place in the cell. They are also very efficient, reaching efficiencies of 60 percent in space applications.

The disadvantage of this fuel cell type is that it is easily poisoned by carbon dioxide (CO₂). In fact, even the small amount of CO₂ in the air can affect the cell's operation, making it necessary to purify both the hydrogen and oxygen used in the cell. This purification process is costly. Susceptibility to poisoning also affects the cell's lifetime (the amount of time before it must be replaced), further adding to cost.

Cost is less of a factor for remote locations such as space or under the sea. However, to effectively compete in most mainstream commercial markets, these fuel cells will have to become more cost effective. AFC stacks have been shown to maintain sufficiently stable operation for more than 8,000 operating hours. To be economically viable in large-scale utility applications, these fuel cells need to reach operating times exceeding 40,000 hours. This is possibly the most significant obstacle in commercializing this fuel cell technology.

Molten Carbonate

Molten carbonate fuel cells (MCFCs) are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications. MCFCs are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a



porous, chemically inert ceramic lithium aluminum oxide (LiAlO_2) matrix. Since they operate at extremely high temperatures of 650°C (roughly $1,200^\circ\text{F}$) and above, non-precious metals can be used as catalysts at the anode and cathode, reducing costs.

Improved efficiency is another reason MCFCs offer significant cost reductions over phosphoric acid fuel cells (PAFCs). Molten carbonate fuel cells can reach efficiencies approaching 60 percent, considerably higher than the 37-42 percent efficiencies of a phosphoric acid fuel cell plant. When the waste heat is captured and used, overall fuel efficiencies can be as high as 85 percent.

Unlike alkaline, phosphoric acid, and polymer electrolyte membrane fuel cells, MCFCs don't require an external reformer to convert more energy-dense fuels to hydrogen. Due to the high temperatures at which they operate, these fuels are converted to hydrogen within the fuel cell itself by a process called internal reforming, which also reduces cost.

Molten carbonate fuel cells are not prone to carbon monoxide or carbon dioxide "poisoning"—they can even use carbon oxides as fuel—making them more attractive for fueling with gases made from coal. Although they are more resistant to impurities than other fuel cell types, scientists are looking for ways to make MCFCs resistant enough to impurities from coal, such as sulfur and particulates.

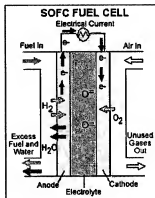
The primary disadvantage of current MCFC technology is durability. The high temperatures at which these cells operate and the corrosive electrolyte used accelerate component breakdown and corrosion, decreasing cell life. Scientists are currently exploring corrosion-resistant materials for components as well as fuel cell designs that increase cell life without decreasing performance.

Solid Oxide

Solid oxide fuel cells (SOFCs) use a hard, non-porous ceramic compound as the electrolyte. Since the electrolyte is a solid, the cells do not have to be constructed in the plate-like configuration typical of other fuel cell types. SOFCs are expected to be around 50-60 percent efficient at converting fuel to electricity. In applications designed to capture and utilize the system's waste heat (co-generation), overall fuel use efficiencies could top 80-85 percent.

Solid oxide fuel cells operate at very high temperatures—around $1,000^\circ\text{C}$ ($1,830^\circ\text{F}$). High temperature operation removes the need for precious-metal catalyst, thereby reducing cost. It also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system.

SOFCs are also the most sulfur-resistant fuel cell type; they can tolerate several orders of magnitude more sulfur than other cell types. In addition, they are not poisoned by carbon monoxide (CO), which can even be used as fuel. This allows SOFCs to use gases made from coal.



High-temperature operation has disadvantages. It results in a slow startup and requires significant thermal shielding to retain heat and protect personnel, which may be acceptable for utility applications but not for transportation and small portable applications. The high operating temperatures also place stringent durability requirements on materials. The development of low-cost materials with high durability at cell operating temperatures is the key technical challenge facing this technology.

Scientists are currently exploring the potential for developing lower-temperature SOFCs operating at or below 800°C that have fewer durability problems and cost less. Lower-temperature SOFCs produce less electrical power, however, and stack materials that will function in this lower temperature range have not been identified.

Regenerative (Reversible) Fuel Cells

Regenerative fuel cells produce electricity from hydrogen and oxygen and generate heat and water as byproducts, just like other fuel cells. However, regenerative fuel cell systems can also use electricity from solar power or some other source to divide the excess water into oxygen and hydrogen fuel—this process is called "electrolysis." This is a comparatively young fuel cell technology being developed by NASA and others.

Fuel Cell Comparisons

	MCFC	PAFC	PEMFC	SOFC
Electrolyte	Molten carbonate salt	Liquid phosphoric acid	Ion exchange membrane	Solid metal oxide
Operating Temperature	1100–1830°F (600–1000°C)	300–390°F (150–200°C)	140–212°F (60–100°C)	1100–1830°F (600–1000°C)
Reforming	External/Internal	External	External	External/Internal
Oxidant	CO ₂ /O ₂ /Air	O ₂ /Air	O ₂ /Air	O ₂ /Air
Efficiency (without cogeneration)	45–60%	35–50%	35–50%	45–60%
Maximum Efficiency (with cogeneration)	85%	80%	60%	85%
Maximum Power Output Range (size)	2 MW	1 MW	250 kW	220 kW
Waste Heat Uses	Excess heat can produce high-pressure steam	Space heating or water heating	Space heating or water heating	Excess heat can be used to heat water or produce steam

Electrochemical reactions of the Fuel Cell types

